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SYSTEM REALIZATION FOR COLLABORATIVE VEHICLE WEIGHT TARGETING AND CASCADING

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ABSTRACT

One of important characteristics of modern ground vehicles is the maneuverability. Excessive size and weight might result in an obstacle to impede the maneuverability of the ground vehicles. Weight should be consistently and efficiently propagated from top-level design specifications to the various subsystems and components. Furthermore, in a ground vehicle development environment, the weight targeting requires heterogeneous departments to interact with each other concurrently and collaboratively. In this paper, therefore, we propose a web-based system to support the ground vehicle weight targeting and cascading for ground vehicle engineers. The system enables weight efficiency calculation with formulae to determine weight and cost targets via competitive vehicle analyses in early product development stages. We implement the proposed system by employing the web technology, which allows collaborative information collection and sharing. With the newly introduced paradigm, the system takes into consideration the various stakeholders who need to access vehicle weight information. Via the suggested information system, vehicle weight information and efficiency metrics (or formulation) are integrated and managed for weight targeting and cascading practices, with associated information and metrics designed to be congruent with a corporation's enterprise-wide decisions. For the purpose of the system's validation, we implemented the system on a vehicle manufacturer's network and discuss the test results, which were based on large-scale vehicle data.

INTRODUCTION

With faster and higher demands of new and variant products, companies are required to participate in global design chains and to collaborate with each other to gain competitive advantages. A wide range of system requirements affect the final product: design, environmental concerns and standards, dynamics, variability, comfort, safety, infotainment, cost effectiveness, etc. The demand for environment-friendly products and cost effectiveness is especially important, and the reduction of fuel consumption is considered as a solution (Leohold and Gottwaldt 2009). This dynamic development environment makes the innovation process more challenging. Even though system integrators and large suppliers are implementing more tailored product development systems to improve effectiveness, the truly innovative development system can only be accomplished by the integrated and efficient operation of complex information embedded in the final design.

Weight targeting and cascading is the term for consistently and efficiently propagating desirable, top level, weight-efficient design specifications to the appropriate specifications for the various subsystems and components (Kim et al. 2003). Its main purpose is to determine weight and cost targets via competitive vehicle analyses in early product development stages. Kumar et al. (2006) presents a hierarchical, multilevel optimization approach based on decision-based design and analytical target cascading, to integrate enterprise-level product planning with engineering-level product development. Analytical target cascading is adopted in the work of Michalek et al. (2005) to explore interrelationships and to formalize the process of coordination between marketing and engineering design problems. Mori et al. (2005) describes a process to cascade interior sound quality targets to noise and vibration control at the system level, and Cooper et al. (2006) demonstrates analytical target setting and cascading with a hybrid electric truck example. However, existing research does not address how the formulations and information associated to weight targeting and cascading are integrated.

This paper discusses how a web-based information-driven approach can integrate information and formulation associated to the current vehicle weight targeting and cascading practices. Via the suggested information system, vehicle weight information and efficiency metrics (or formulation) are integrated and managed for weight targeting and cascading practices, with associated information and metrics designed to be congruent with a corporation's enterprise-wide decisions. The proposed system is implemented using web scripting technology and tested with a cooperate database.

LITERATURE REVIEWS

The mechanical product industry is under tremendous pressure to create more variety to attract customers. In this inexplicable product development environment, global manufacturing companies outsource components and subsystems to suppliers around the globe. Thus, product structures are re-defined to increase flexibility and scalability, and to share more components among different products to achieve the large production volumes. Muffato and Roveda (2002) note that a modular architecture can allow the externalization of some phase of the production; products can thereby be flexibly produced and managed.

In the global product development environment, collaboration is a vital question. Booch and Brown (2003) describe a Collaborative Development Environment (CDE), a virtual space wherein all project stakeholders, separated by time or distance, may negotiate, brainstorm, discuss, share knowledge, and work together to accomplish some task. Most often it means the virtual space to create an executable deliverable and its supporting artifacts. CDE is especially useful in a space where engineers work together to resolve a problem. Booch and Brown (2003) present the current features required for a fully functioning CDE and the conceptual three categories and how organizations work successfully with all the features in CDE. Similarly, Milne and Winograd (2003) provide a workspace concept for the collaborative environment. They discuss the research issues relating to design; how digital information enters a design workspace, and how affordances can be provided. To do so, it is necessary to address a variety of new technologies, as well as how to define a technology affordance. Among collaborative environment challenges, research emphasizes that customers and stakeholders should be involved from the conceptual design of product development, in terms of increased customer satisfaction. One example of this is customer involvement in personal mobile devices targeted for seniors (Eisma et al., 2004).

Globalization has deeply affected what direction innovation takes (Thoenig and Verdier 2003) and where it takes place geographically (Roman et al. 2008). Thoenig and Verdier (2003) suggest that, since the market has gone global, increased competition and technological imitation (or leapfrogging) leads to firms biasing their innovations towards skilled labor technology. Parts or technologies that cannot be copyrighted are still somewhat difficult to imitate if the innovations are biased towards skilled labor rather than unskilled labor. Today's innovation is mainly led by the multinational enterprises (Narula and Zanfei 2004). These enterprises pour billions of dollars into research and development every year. One automobile OEM alone invested U$6.8 billion and thus was on the top ten lists of global companies (Roman et al. 2008). Innovation and development clearly play a critical role.

What sets the ground vehicle industry apart from other industries, however, is that it is operated by an oligopoly of industry giants. The cost of innovation is too high for smaller businesses—vehicle development takes over 30,000 engineering hours, has a 3-5 year project cycle, and costs billions of dollars in initial investment. Smaller businesses are unable to complete such challenging tasks since they cannot acquire sufficiently large amounts of capital (Leohold and Gottwaldt 2009). Thus, the ground vehicle industry enjoys huge investments in R&D that is very focused, unlike other industries in which small businesses may compete with each other but lack the focus on one particular technology.

In the area of consumer goods, corporate strategies strive to capture customers' voices. Like any consumer products, the auto industry also tries to reflect customer demands in their products to ensure sales and customer satisfaction. With faster and higher demands of new and customized products, companies are required to participate in global design chains and collaborate with each other to gain competitive advantages (Fan et al., 2008). Leohold and Gottwaldt (2009) identify the wide range of customer demands that affects the final product, such as: demands on design change, environmental concerns and standards, dynamics, variability, comfort, safety, infotainment, and cost effectiveness. While global economical depression and fuel cost increases have affected customers' buying decisions, environment-friendly products and cost effectiveness are very important requirements (Leohold and Gottwaldt 2009).

The growing demand for more fuel-efficient vehicles to reduce energy consumption and air pollution is a challenge for the ground vehicle industry. A key factor in fuel consumption is the vehicle's weight. There has been an increased effort by companies to meet their fuel consumption goals by reducing the weight of their vehicles. Since average vehicle weight is expected to increase and the ground vehicle industry will continue to market new models, weight reduction is particularly important. Safety features such as anti-block systems, and increasing safety body structure contribute to vehicle weight gain. Although, the vehicle companies have responded to this by improving design and power train efficiency, these incremental improvements have not yet enabled a significant reduction in overall weight (Miller et al., 2000). A 10% weight reduction equals approximately a 5.5% improvement in fuel economy (Cole et al., 1997). Weight reduction, which has a ripple effect on fuel efficiency, is an important fact in auto industry. For example, weight reduction enables the manufacture to develop the same vehicle performance with a smaller engine, and such a smaller engine enables the use of a smaller transmission and a smaller fuel tank. Therefore, it is estimated that 10% of vehicle weight reduction results in 5–10% of fuel economy improvement (Morita, 1998).

COLLABORATIVE VEHICLE WEIGHT TARGETING AND CASCADING

The main purpose of weight targeting and cascading is to determine weight and cost targets by competitive vehicle analysis in the early stage of product development. Weight targeting and cascading uses target settings and propagations of the desirable top level design specifications for weight efficiency, communicated via appropriate specifications for the various subsystems and components (Kim et al. 2003). In a collaborative weight targeting process, Figure 1 illustrates a proposed data flow that help support product engineers in collaborative environments to understand systems' big figure weight targets. To set appropriate weight targets, the process requires collaborative information from various product engineers. The Weight Efficiency Metrics Application (WEMA) is a collaborative decision supporting system that provides information related to vehicle weight efficiency (body structure, package, etc.). After setting the weight target for the top level (e.g., Body in White (BIW) structure), the desirable weight target of the top level propagates to various subsystem and components (e.g., underbody, front end, body side, closures, roof, dash panel, front floor, rear floor, rear wheel house, etc). Figure 2 shows an example of the sub-systems of the BIW structure and the weight targets can be determined for these sub-systems by utilizing WEMA.

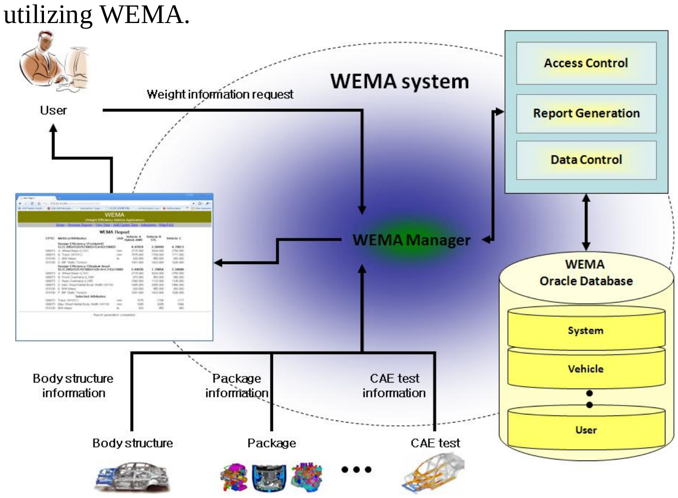


Figure 1 Data flow in collaborative weight targeting process

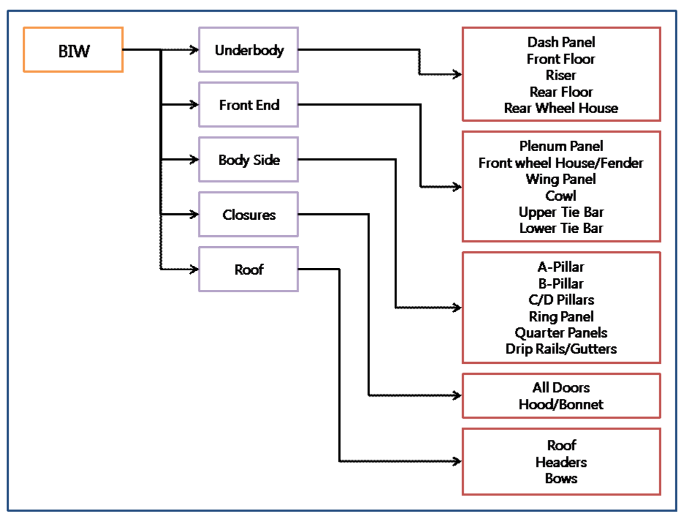


Figure 2 Weight target propagation example (BIW structure)

The current weight targeting process workflow (before the WEMA is implemented) is based on an Excel spreadsheet, which gathers individual data sources from various teams and then calculates weight efficiency (see Figure 3). For example, to calculate body structure weight share of max curb weight, the engineer has to collect data sources such as packaging data, competitors' vehicle data, weight data, and/or test performance from various teams because each input is managed by an individual team, which means the data sources are distributed throughout the company. If benchmarking and physical testing data is required, the engineer must ask benchmarking, packaging, advanced engineering, and advanced product development teams to gather the data, while when engineering data comes into request, the engineer then must obtain the data from the packaging, advanced product development, and engineering teams. Once the engineer gathers all the necessary data, which is raw data, the data is then reorganized and the engineer generates efficiency metrics to calculate various weight factors. After working through this complicated information flow, the engineer generates a report. Unnecessary weight efficiency summary reports are unfortunately frequently regenerated due to data inconsistency or frequent data and metrics updates.

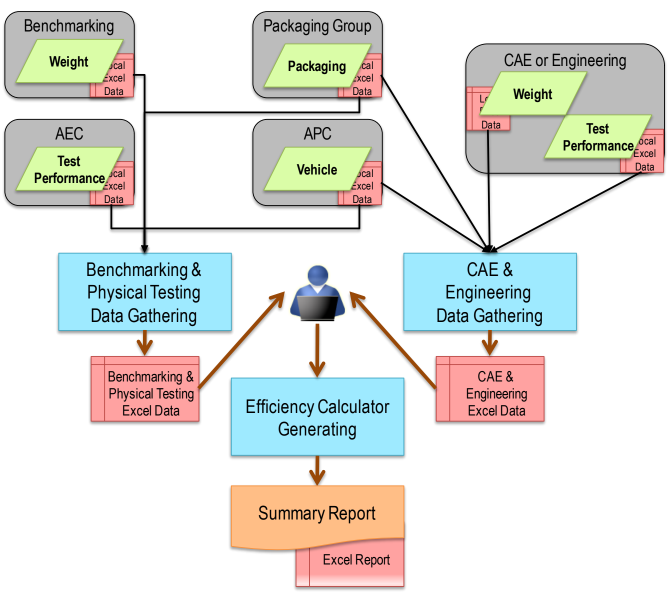


Figure 3 Current weight targeting process

Figure 4 illustrates the proposed process with WEMA, which shows how the system integrates all the data into a single place managed by an administrator, while individual teams take responsibility for only providing a raw data. By doing so, information flows are connected and the individual engineer no longer is solely responsible of the integrity of information with frequent data and metrics updates. Integrated data and solid decision-making are available for real-time weight targeting. For example, a Body Structure Efficiency Calculator report requires a time-consuming process to obtain relevant metrics: for footprint design efficiency from testing and packaging group; for shadow area design efficiency and package efficiency to torsional performance from packaging group; for body structure, closures, and sheet metal from engineering team. By implementing WEMA, however, domain-specific metrics can be concurrently managed and shared without delay so that any kind of weight targeting and cascading report can be generated from the integrated metrics and data.

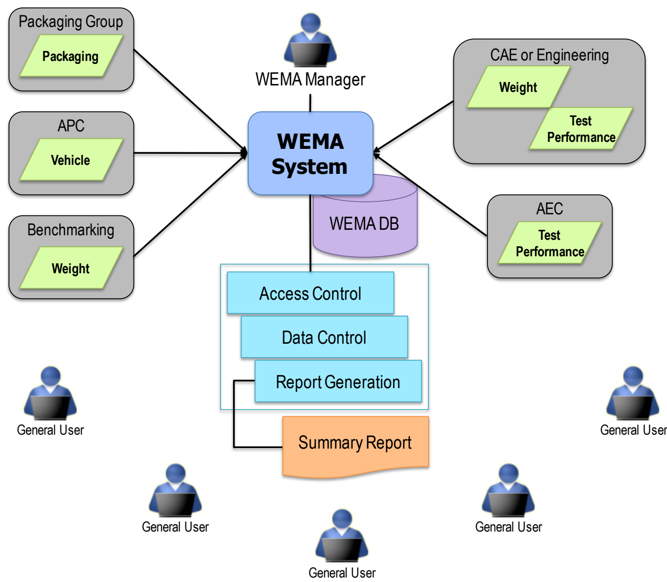


Figure 4 New weight targeting process with the WEMA system

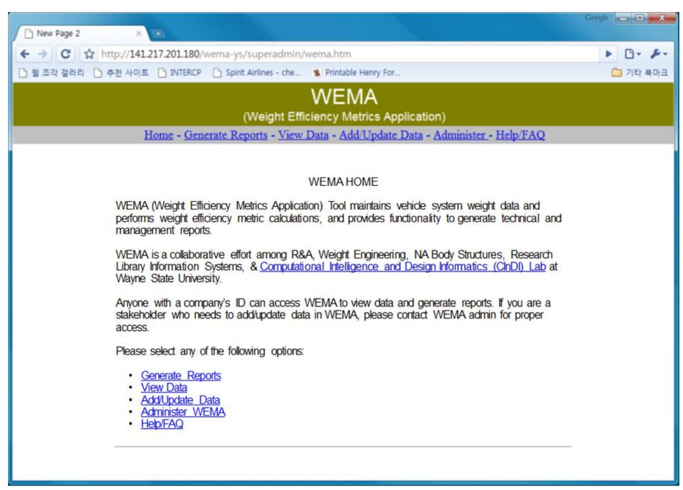
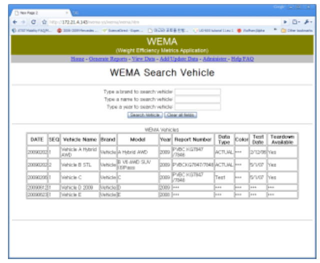


Figure 5 The main page of WEMA's super-adminsitrator

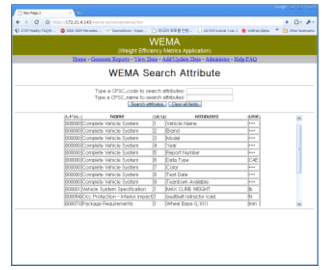
To realize a secure collaborative environment, WEMA's access control module validates the user's access level and selectively allows display and modification of information. WEMA is based on a single login, meaning that user's access level is automatically detected by the user's login ID. As noted previously, the system functions are different for each of the four user types (observer, participant, administrator, super-administrator). Figure 5 shows the main page of WEMA's super-administrator with four main functions: generate report, view data, add/update data, and administer. When the super-administrator logs in, he or she can search the WEMA data, vehicles, systems, system attributes, and metrics. The vehicle system and weight information (e.g., body structure, package, and CAE test information) of the vehicle is collected collaboratively and is sent to WEMA. The data control module handles the weight information to be stored in the WEMA database for appropriate systems.

When vehicle weight efficiency information is requested for comparison to multiple vehicles and their weight targets, WEMA provides a comparative report with weight information on multiple vehicles. For example, a WEMA user wants to compare the body structure weight information of vehicle A with competitive vehicles, such as vehicles B and C. The weight information of vehicle A, which is obtained from body structure department, is sent to WEMA. WEMA's database already has the body structure information for vehicles B and C, which is obtained from suppliers or other departments. Then, a weight efficiency report can be generated by WEMA for the comparison of three vehicles. (A note to the reader: data presented below is based on an actual implementation but has been modified to protect confidential information.)

To further illustrate WEMA's functions, a design efficiency calculation example is used. A design efficiency metric, which includes footprint and shadow area, is a measure to represent the relationship between design and weight. If a user wants to compare the design efficiency of user's vehicle (vehicle C) with a competitor's vehicles (vehicles A and B), first, the user selects "View data," which has four functions: view vehicles, view systems, view attributes, and view metrics. "View vehicles" and "view attributes" each display vehicle information and attributes available in WEMA's database (Figure 6). If any information does not exist, the user can add new information via "add/update data." Figure 7 (a) shows the information input process for attribute values of vehicle A. After adding attribute values, the user may click "view metrics" to find design efficiency metrics (Figure 7 (b)). Now all information is ready for comparing vehicles' design efficiency based on weight targets. The user chooses "generate report," and searches vehicles (vehicle A, vehicle B, and vehicle C), Metrics (Design Efficiency (Footprint) and Design Efficiency (Shadow Area)), and attributes if needed (Figure 7 (c)). Figure 7 (d) shows a report of comparison of design efficiency among the vehicles.



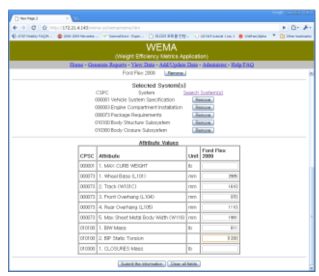
(a) View Vehicles



(b) View Attributes

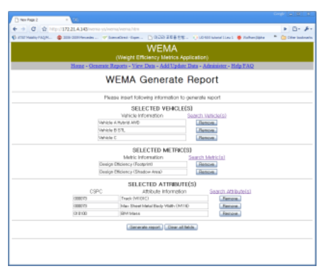
Figure 6 Examples of View Data

As shown in Figure 7 (d), the footprint design efficiency of vehicle C is higher than vehicle B; however it is lower than vehicle A. This implies that the user's vehicle has a lower footprint design efficiency in comparison to vehicle A. A similar situation is indicated in the shadow area design efficiency; also, the BIW mass of vehicle C is heavier than vehicle A. Based on this analysis result, the product engineer can indicate the current standing of vehicle C. After this analysis, the vehicle development team can make a decision at the system level, such as how much weight reduction is required. Based on this system-level decision, the each subsystem and components weight reduction target can be cascaded.

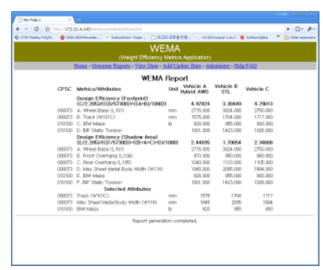


(a) Add attribute values

(b) View Metrics



(c) Selection for Generate Reports



(d) WEMA report for design efficiency

Figure 7 WEMA processes

DISCUSSIONS

Current practices for weight targeting and cascading is typically based solely on an Excel spreadsheet which has several obvious limitations, including having low flexibility for metrics updates as well has being sub-optimal in terms of time efficiency and the need for data entry. It has a fixed layout and shows a column-based comparison of vehicle attributes among only three vehicles. If the number of vehicles and metrics need to be increased or updated, it requires new Excel template development, which can have a significant delay in weight targeting and cascading. To improve this current process, we developed a new software tool, WEMA; we tested it on an OEM's internal network and linked the software to the OEM's database. The beta test was conducted for benchmarking. As the result of the beta test, the company's vehicle and other competitor's vehicle were compared via WEMA and the benchmarked data was used for their weight targeting. The data used for the beta test included about 33 vehicles, 900 systems, 85 attributes, and 12 metrics. Among 900 systems, four systems were selected for this test and 85 attributes are detailed for the four systems. WEMA was tested with an administrator and multiple participants. The administrator used the functionality of WEMA at the administrator level. Participants uploaded the data from the Excel spreadsheets provided by domain experts and validated the functional aspects of WEMA at participant levels.

Table 1 Comparison of the current approach and WEMA approach

Current approach	WEMA approach
• Spreadsheet-based system • Data duplication in each engineer's workstation • Less of data control and security • Lack of scalability on the size of data growth • Difficult to add/update/share data • Difficult to build and maintain additional metrics	• Collaborative web-based application • Single source of data • Data accuracy and ownership can be controlled • Highly scalable and flexible in data and functionality (e.g., data mining and analysis functionality) • System available to all the employees around the world • Efficient to update attributes/metrics

Based on the beta test, the biggest advantage of WEMA over the current Excel-based approach is the control of data and metrics. Any time a new set of data is added, it is stored in a common corporate database. This database is managed by internal product data management systems which avoids the problem of several people making changes on different versions. Also, any additional data received would be difficult to get captured in a single main spreadsheet. However, WEMA has an edge over the current approach in selecting only the necessary data and metrics for comparison and generating a report so the user has a clear understanding of a current vehicle's weights and of system-level weight targeting. The comparison of current approach and WEMA is summarized in Table 1. This summary has been refined with the discussion of the company implemented the WEMA system. The quantitative data was not able to be included in this article, since the company does not want to publicize the information. However, overall, WEMA's enhanced functionality and functions were well recognized by domain experts throughout the beta test.

Through WEMA, collaborators can remotely provide vehicle weight information to all the processes in product design and development. By continuously and collaboratively feeding vehicle weight information to all the processes, product engineers have the benefit of an information-based approach. To support collaborative weight targeting and cascading, WEMA provides a competitive vehicle assessment environment by remotely collecting and sharing relevant weight information. Vehicle information is maintained a synchronized database to help ensure information consistency.

CONCLUSIONS

With an information-driven paradigm, WEMA takes into consideration the various stakeholders who need to access vehicle weight information. With current systems, the same broad range of stakeholders can sometimes cause complicated relationships for accessing and managing the vehicle weight information. During WEMA's development, user types and roles were analyzed and determined. We conducted a UML-based system analysis to conceptualize WEMA and its system architecture. It is implemented using CGI, PERL, Apache 2, Oracle 9i, and UNIX. For collaborative weight targeting process, WEMA provides a data flow that supports product engineers' understanding of weight targets for various vehicle systems. It is a collaborative decision supporting system that provides various information related to vehicle weight efficiency, such as body structure, package, etc. After installing into an actual manufacturer's (OEM) database, we found that WEMA is a significant improvement over the current Excel-spreadsheet based approach. The current approach is cumbersome and time consuming for data entry and has very low flexibility for metrics update, whereas WEMA allows ubiquitous control of vehicle and weight data. The domain experts who participated in a beta-test agree that the WEMA provides a clear and synchronized understanding of current vehicle's weights and of system-level weight targeting.

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